TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 272

EXPERIMENTS WITH A DEVICE FOR SHORTENING

THE GLIDE AND LANDING RUN OF AN AIRPLANE.

From "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part II, 1923.

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EXPERIMENTS WITH A DEVICE FOR SHORTENING THE GLIDE AND LANDING RUN OF AN AIRPLANE.*

Object of the experiments.- The improvement of airplanes and increased safety of air traffic can be sought in various ways. In the experiments described below, the aim was to find some simple and inexpensive method of modifying present-day airplanes, so as to improve and simplify the process of landing.

So long as airplanes must run a long way on the ground before coming to rest, landing fields must be large and forced landings will be dangerous. In this connection, account must be taken of the so-called "gliding-angle", i.e., the angle at which the airplane can descend, after the engine has stopped. An airplane is generally considered safer the farther it can glide from a given altitude before landing. Thus there is more time to seek a landing place and to choose between different fields.

The pilot must then exercise great care that the horizontal velocity, with which he approaches the ground, remains below a certain limit, since otherwise the attempt to land with the tail on the ground, whereby the angle of attack is increased, may cause the airplane either to rise again or press too lightly on the ground. In most cases the landing run of such an airplane is long.

* From "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part II, 1923, pp. 3-12.

With the device described below, it was found that the pilot, by a simple manipulation, could so modify the character of the wings as to change the angle of glide of the airplane and thus considerably shorten the landing run. This was effected by increasing the drag and decreasing the lift of the wings, so that the beginning of the run could be much swifter, without danger of rising again.

This report gives the results of wind-tunnel experiments with this device and the calculation of the expected improvement based on them.

I. Principles on which the device is based.- It is apparent from the various experiments that even a slight disturbance of the flow over the top of a wing may exert, under favoring circumstances, a great influence on the whole flow.* At the place where the disturbance occurs, vortices are formed which deflect the normally smooth flow from the upper surface of the wing. These vortices spread out laterally, while the flow carries them along the top of the wing. This causes a local flow resembling that produced by a wing above the critical angle of attack. This change in the nature of the flow usually increases the drag and decreses the lift.

* "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part II, 1923, pp. 13-33, "Experiments on the influence on the aerodynamic properties of cutting away part of the leading edge of a Fokker FIII wing"; also N.A.C.A. Technical Memorandum No. 103, "Effect of Structure in Middle Part of Leading Edge of a Thick Wing."

Advantage may be taken of this phenomenon to shorten the landing run. If, while the airplane is running on the ground, such a disturbance is introduced, the retarding forces are thereby increased. The drag retards directly, while the decrease in the lift also acts like a brake by increasing the pressure of the wheels and tail-skid on the ground. It is also possible, by such a device, to shorten the glide before landing, since any reduction of the lift-drag ratio increases the angle of attack.

Such a disturbance can be produced by a number of flaps, which, in normal flight, lie on or in the upper surface of the wing and which can be raised while gliding or landing. The purpose of the experiments was to determine whether this braking effect is sufficient to warrant the use of some such device on actual airplanes and, if so, how to arrange the flaps in order to obtain the best results.

II. Description of the models.- A 1:20 mahogany model of the wing of a Fokker FII airplane (Wing model No. 14) was used for the experiments.* Fig. 1 shows the plan of the model, together with the different arrangements of the flaps, each arrangement being given a special letter. The flaps were thin copper rectangles 9 x 20 mm (0.354 x 0.787 in.). Thus they have the same proportions as the 180 x 400 mm (7.09 x 15.75 in.) flaps on a full-sized air-

* The tests of the aerodynamic properties of this model were published in Report A19, "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part I, p.74.

plane. On the first models, the flaps were connected by a 1.5 mm (.059 in.) copper wire, which was securely soldered to the rear side at half the height. About 5 mm (0.2 in.) outside the outermost flaps, the wire was bent at right angles. The ends were pointed and served to hold all the flaps snugly against the model. Since it was found, in these experiments, that this manner of fastening exerted an appreciable influence, in subsequent experiments with models h to m each flap was secured separately with the aid of a pin soldered firmly to its rear side. On all the models, the surface of the flaps was perpendicular to the plane of the wing chords and parallel with the wing spars. The lower edges of the flaps lay in the upper surface of the wing, with the exception of model j in which there was an intervening slot of 1 mm (0.04 in.).

III. Experiment and calculation methods.- The experiments were executed in the R.S.L. (Rijks-Studiedienst voor de Luchtvaart) wind tunnel with a wind velocity of about 27.5 m (90 ft.) per second. The mean chord of this wing was 129.5 mm (5.1 in.), so that the value of Vl was accordingly 3.56 sq.m (38.32 sq.ft.) per second. The wind forces were measured with the Eiffel balance at angles of incidence of 8°, 12° and 16°. These angles of incidence were chosen, because the angle of incidence of this airplane, when resting on its wheels and tail-skid on a level surface, is about 12° and angles in this vicinity are accordingly of importance for the glide. The way these wind forces were determined has already been described.*

The lift and drag coefficients were calculated from the measured forces with the aid of the formulas:

$$R_y = C_y \frac{\gamma}{g} O V^2$$

$$R_x = C_x \frac{\gamma}{g} O V^2$$

in which:

R_y = lift or vertical component of wind force in kg;

R_x = drag or horizontal " " " " " "

C_y and C_x = respectively the absolute lift and drag coefficients;

γ = density of air in kg per cubic meter;

g = acceleration due to gravity in m/sec^2;

O = upper surface of wing in m^2;

V = relative wind velocity in m/sec.

Moreover, in a few special cases, the landing run and the speed during this run were calculated with the aid of the formulas:**

$$l = \frac{1}{2A} \frac{A V_o^2 + B}{B}$$

$$V^2 = -\frac{B}{A} + \left(V_o^2 + \frac{B}{A}\right) e^{-2Ax}$$

in which:

l = length of landing run in meters;

V_o = speed of airplane when it touches the ground, i.e. ....

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* Report A7, "Verslagen en Verhandelingen van den R.S.L., Part I, p.43.

** Reyneker, "Het landen van vliegtuigen" (Landing of airplanes), "Het Vliegveld," March, 1922, p.56.

the "landing speed" in m/sec;

x = distance in meters covered on the ground before reaching the speed V ($x = l$ when $V = 0$).

$$A = \frac{\gamma}{g}\, O\, \frac{C_x - f C_y}{m} \qquad B = fg$$

f = coefficient of friction between wheels and tail-skid and the ground.

m = mass of airplane in kg sec^2/m.

In applying these formulas, attention should be paid to the following facts:

1. They apply only for constant values of C_x and C_y and therefore for a constant angle of incidence during the landing run. It is here assumed that the wheels and tail-skid touch the ground at the same time and that the angle of incidence is 12°.

2. The value of the coefficient of friction f is indeterminate, since it depends on the condition of the landing field and the distribution of the forces between the wheels and tail-skid. f is here assumed to be 0.1, as a fair value corresponding to the measurement of the length of several landing runs..

3. In these experiments, the center of pressure of the wind forces was not fixed, thus leaving an uncertainty in the above-mentioned distribution of forces. This was disregarded in the calculation for the following reason, namely, that the landing run can be divided into two parts, the first part at a high speed and the second at a low speed. During the first part the greater retarding

force is the drag, while during the latter part it is the friction with the ground. In the first part the lift is great, so that the location of the center of pressure may have considerable influence on the distribution of the forces exerted on the wheels and tail-skid. The retarding force of the friction, however, is so small that any moderate change in the force distribution f has little effect. In the latter part the lift is small and the force distribution is decidedly affected by the location of the center of gravity. Any important modification of f is not to be expected here.

4. In the calculations, use was made of the results of the experiments with the models. No correction was made for a possible vl effect, so that the calculated results have only a comparative value.

The effect of decreasing the lift-drag ratio can be judged as follows. From the previous equilibrium values of the forces acting on the airplane in gliding with the engine stopped, it follows that the lift-drag ratio is equal to the cotangent of the angle of glide, thus

$$\alpha = b\ g\ \cot \frac{C_y}{C_x} .$$

The angle of glide is the angle with the horizontal made by the flight path of the airplane. The horizontal projection ij of the flight path made by an airplane in gliding from an altitude h is

$$ij = h \cot \alpha = h \frac{C_y}{C_x}.$$

This distance is therefore proportional to the lift-drag ratio (Fig. 2).

IV. Experimental results.- The values of the lift and drag coefficients and of the lift-drag ratio are given in Table I. As already mentioned, the incidence of 12° is important for shortening the landing run. Hence only this incidence will be used here for comparing the lift and drag coefficients. In Fig. 2 the results for $i = 12°$ are represented in the following manner. For each model the increase of C_x and the decrease of C_y are expressed in percentages of the coefficients of the original model. The horizontal lengths of the rectangles represent their relative magnitudes, while the accompanying numbers indicate the percentages increase or decrease.

In the following exposition these percentages will be employed as comparative values, unless otherwise indicated. In Fig. 2, for better mutual comparison, the models are assembled in several groups (A to E). Moreover, Table II gives the numerical values of the increases and decreases for the important group E.

Effect of distance of flaps from leading edge of wing (group A, models a to d).- Distances of 10 and 20 mm (0.39 and 0.79 in.) (Models a and b) give practically like results, but further increase in the distance diminishes the effect of the flaps (models c and d). Model c, however, is structurally the best for the airplane under consideration, since the flaps are here located over the leading edge of the front spar. The loss of effect in comparison with a and b (8% of C_x and 3% of C_y) is more than offset by its structural advantages.

Effect of the number of flaps and their distance from one another, with the use of a connecting-rod (Group B, models b, e, f, g).- Increasing the number of flaps increased the effect. On the other hand, the removal of the middle flap produced a remarkable effect. When the middle one of three flaps was taken away (models b and f), both lift and drag were increased about 5%. Removing the middle one of five flaps increased the lift 6%, while the drag remained practically unchanged. It was thought these results might be due to the influence of the connecting rod.

Effect of connecting rod (Group C, models g and h).- These models differed only in that the connecting rod was lacking in model h, which resulted in a 14% decrease in the drag and a 4% increase in the lift. Since the connecting rod would not be employed on full-sized airplanes, it was left off in the subsequent models (h to m). By comparing models b and h, we found that two flaps far apart produced a greater effect than three near together. This showed that the effect of a flap spread out laterally and that the disturbed regions overlapped one another in the latter case (model b). It was found that the disturbed region spread out at an angle of about 45° to the direction of the wind.

Effect of having a slot under the flap (Group D, models i and j).- For structural reasons, it may be necessary to leave a slot between the flap and the top of the wing. A slot one millimeter wide, with this model, lessens the drag 5% and the lift 4%. This effect, however, does not render the slot inadmissible.

Determination of the best practical form (Group E, models h, i, k, l, m).- For practical use, it is advisable, with this airplane, to place the flaps over the front wing spar. This arrangement somewhat lessens the effect (See models h and i; also Group B). Moreover, it is desirable to employ as few flaps as possible and to place them as near together as possible. The effect of two flaps (Model i) was not entirely satisfactory and the introduction of a middle flap (Model k) made but little improvement (Compare also group B). The addition of a flap on each end (Model l) made considerable improvement in that it increased the drag 17% and decreased the lift 9%. A still further improvement was effected by increasing the distance between the flaps (Model m). This arrangement increased the drag 6% and decreased the lift 5%. The latter model was therefore adopted, both on account of its aerodynamical characteristics and its convenience of construction. In this model the braking mechanism consisted of five flaps 9 x 20 mm (0.354 x 0.787 in.) placed at intervals of 120 mm (4.72 in.), measured from center to center, on the wing spar. As compared with the original wing, this model, at an incidence of 12°, increased the drag 98% and decreased the lift 36%.

Effect of the lift-drag ratio.- The decrease in this ratio, as compared with that of the original wing, was expressed in % of the latter. Table III gives the decreases for group E at all the angles of incidence, both for the wing alone and for the complete airplane. The latter values were obtained by computing the effect of the fuselage and accessories on the lift and drag. In this connection, use was made of results previously obtained with a model of the Fokker F II airplane.* The lessening of the lift-drag coefficient decreased with increasing incidence. For model "14 m," however, at $i = 16^\circ$, it was still 54°, which thus fully agreed with the one considered in section III, with a 54% shortening of the necessary preliminary glide.

V. Numerical example.- The effect of the landing device (as installed on model m) on the length and speed of the landing run was calculated with the aid of the formulas given in section III. In this connection, use was made of results previously obtained with a model of the Fokker F II airplane.* In the computations for the unmodified airplane, these results were employed without change, but a correction was made for the airplane with landing device, corresponding to the difference in the characteristics of wing models 14 and 14 m. The following data were also adopted for the computations: weight of airplane, $G = 2000$ kg (4409 lb.); upper surface of wing, $O = 42$ sq.m (452 sq.ft.); coefficient of friction, $f = 0.1$; landing speed, $V_o = 22.6$ m (74 ft.) per second. The length of the landing run of the unmodified airplane was 234 m (767 ft.), whereas that of the airplane with the landing device

* Report A 19, "Verslagen en Verhandlingen van den R.S.L.," Part I, p. 74.

was 164 m (538 ft.), or about 30% shorter.

The speed during the landing run is important, when there is danger of collision, as in a forced landing on a small field. The question here is, as to how much momentum the airplane still has after running a certain distance on the ground. In Fig. 3, therefore, the velocities were not plotted as such, but as their squares divided by V_0^2, against the traversed distance x. From this figure it appears that the airplane with the landing device had lost half its momentum at 65 m (213 ft.), whereas the airplane without the landing device did not lose half its momentum until it had gone 108 m (354 ft.). The same airplanes had lost 75% of their momentum at 108 m (354 ft.) and 168 m (551 ft.) respectively.

VI. Conclusions.- By fitting a wing with flaps of dimensions and locations corresponding to model 14 m, the drag, at an incidence of 12°, was increased 98% and the lift was decreased 36%. From the data obtained by experimenting with models, it was calculated that the landing run would be shortened about 30% by erecting the flaps at the moment of landing. The danger from collisions during the landing run was lessened by the more rapid reduction in the speed. It was found that the glide before landing could be shortened about 54%.

Table I.

No. of Mod-el	$i = +8^\circ$			$i = +12^\circ$			$i = +16^\circ$		
	C_x	C_y	C_y/C_x	C_x	C_y	C_y/C_x	C_x	C_y	C_y/C_x
14	0.042	0.592	14.05	0.060^5	0.692	11.41	0.086^5	0.726^5	8.38
14a	0.080^5	0.442^5	5.49	0.108	0.527	4.87	0.137	0.598^5	4.36
14b	0.082	0.421^5	5.16	0.108	0.525^5	4.87	0.137	0.603	4.39
14c	0.080^5	0.445^5	5.56	0.103^5	0.548	5.29	0.131^5	0.620^5	4.72
14d	0.076^5	0.458	5.98	0.101	0.559	5.53	0.128	0.642	5.03
14e	0.094	0.368	3.92	0.118^5	0.451^5	3.81	0.148^5	0.521^5	3.52
14f	0.084^5	0.464	5.48	0.111	0.565^5	5.11	0.134^5	0.622^5	4.63
14g	0.093^5	0.403^5	4.32	0.119	0.490^5	4.12	0.143^5	0.568	3.86
14h	0.085^5	0.422^5	4.97	0.110^5	0.519^5	4.69	0.131	0.597^5	4.57
14i	0.078^5	0.446^5	5.68	0.104	0.544^5	5.23	0.130^5	0.609^5	4.67
14j	0.078^5	0.419	5.33	0.101	0.520^5	5.16	0.127^5	0.610^5	4.79
14k	0.082^5	0.437	5.32	0.106	0.542	5.11	0.136^5	0.582^5	4.28
14l	0.090^5	0.402^5	4.45	0.116	0.477	4.12	0.143^5	0.535^5	3.74
14m	0.094^5	0.376^5	3.98	0.119^5	0.445	3.71	0.147	0.491^5	3.35

Table II.

Model No.	$i = +12^\circ$	
	Increase of C_x in %	Decrease of C_y in %
	for the wing alone.	
14	0	0
14h	83	25
14i	72	21
14k	75	22
14l	92	31
14m	98	36

Table III

Model No.	Decrease of C_y/C_x in %.					
	Wing only			Complete airplane		
	$i = +8^\circ$	$i = +12^\circ$	$i = +16^\circ$	$i = +8^\circ$	$i = +12^\circ$	$i = +16^\circ$
14	0	0	0	0	0	0
14h	65	59	45	59	52	39
14i	60	54	44	53	48	38
14k	62	55	49	56	49	42
14l	68	64	55	62	58	49
14m	72	68	60	66	62	54

Translation by Dwight M. Miner,
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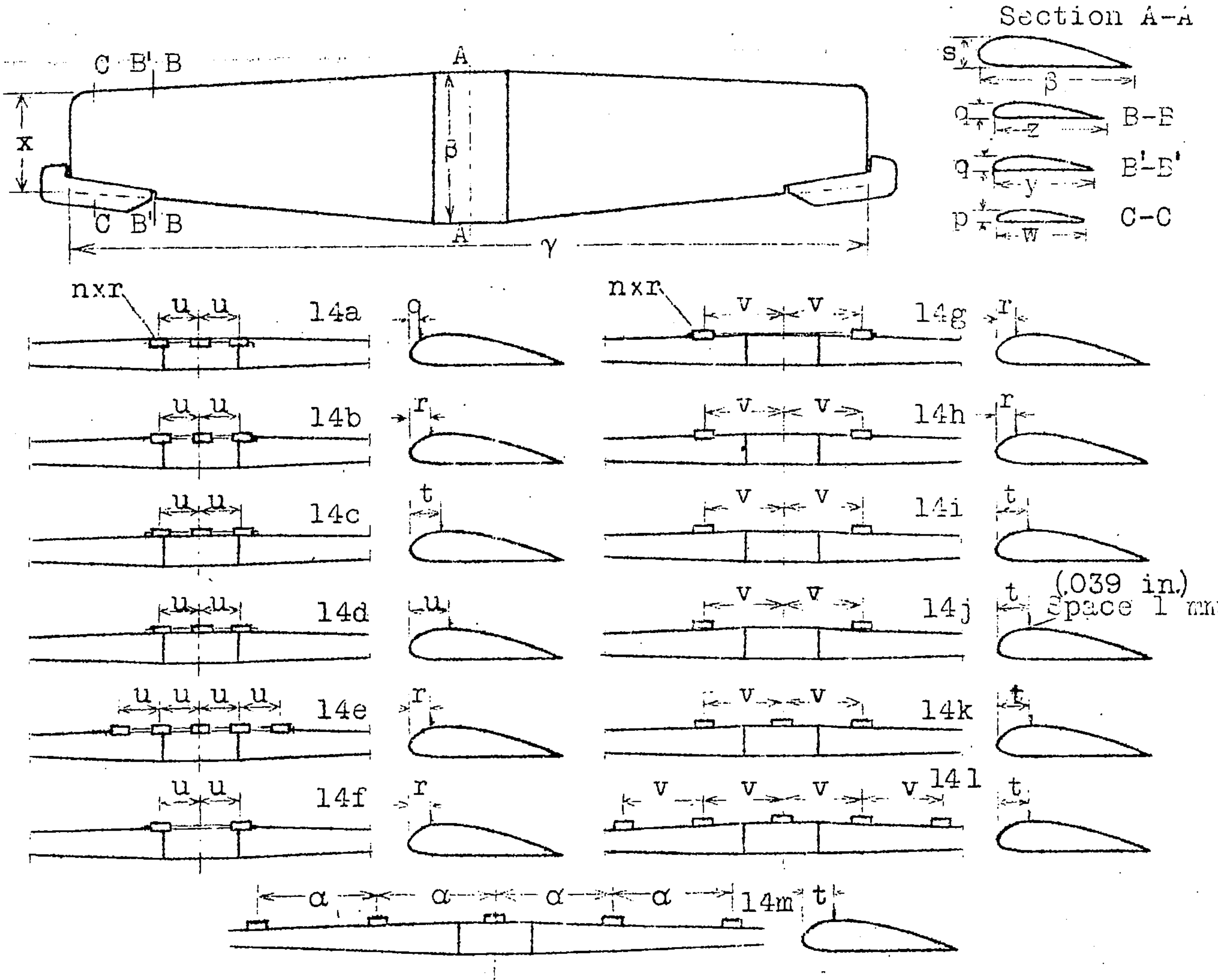

n = 9 mm (.35 in.)		v = 80 mm (3.15 in.)
o = 10 " (.39 ")		w = 92 " (3.62 ")
p = 12.25 " (.48 ")		x = 102 " (4.02 ")
q = 16 " (.63 ")		y = 108 " (4.25 ")
r = 20 " (.79 ")		z = 117 " (4.61 ")
s = 30.8 " (1.21 ")		α = 120 " (4.72 ")
t = 31.5 " (1.24 ")		β = 157 " (6.18 ")
u = 40 " (1.57 ")		γ = 803 " (31.61 ")

Fig.1 Model No.14

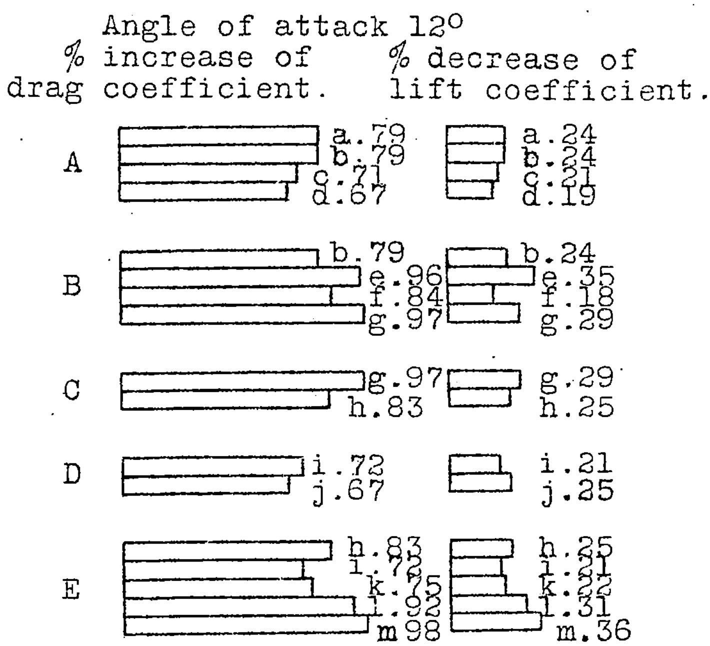

Fig.2 Result of test.

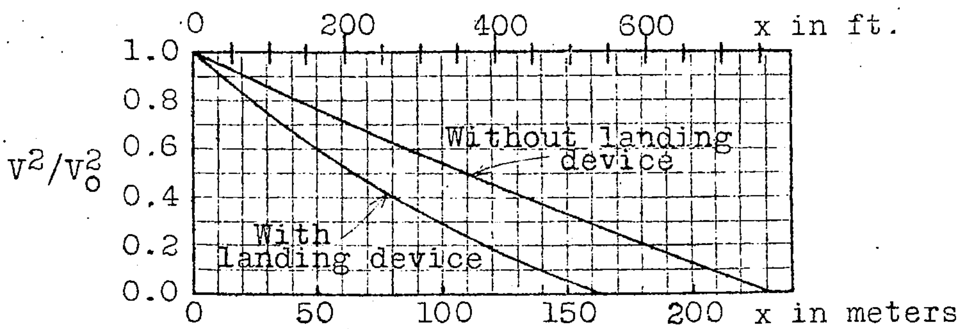

Fig.3 Comparison of momenta during landing run.